A Miniaturized Device to Directly Measure Chemical Composition of Cloud-active Aerosols: A New Method for Determining Sources of Cloud Condensation Nuclei

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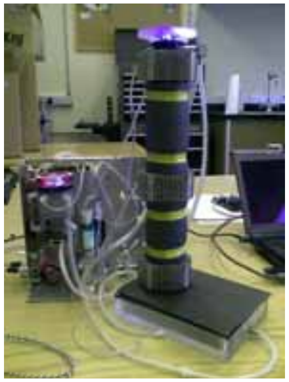

6th Annual Climate Change Symposium

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Outline

- Motivation for research
- What are Cloud Condensation Nuclei (CCN)?
- u-capillary electrophoresis (uCE) for looking at aerosol chemistry
- Coupling uCE w/ CCN & aerosol particles
- Outlook for CalWater

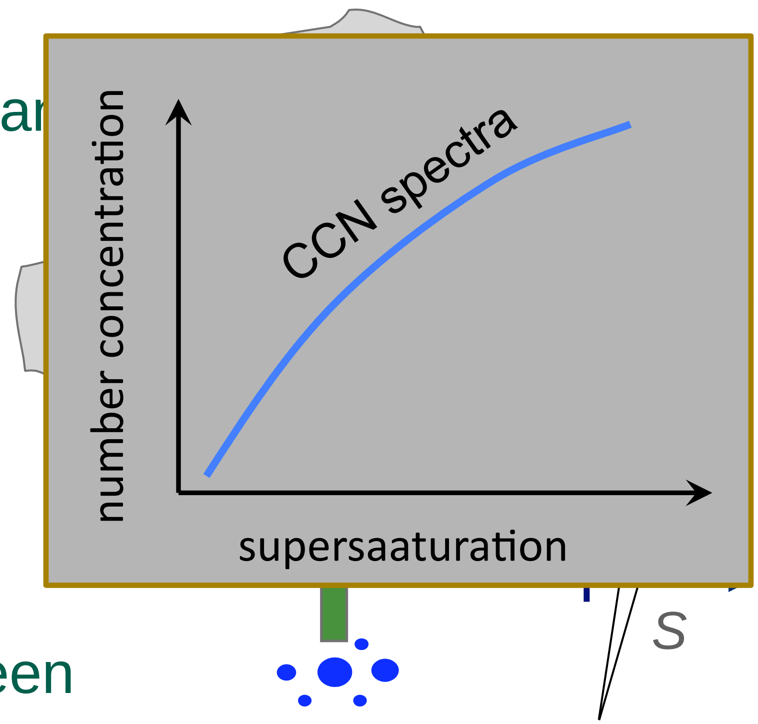
What are cloud condensation nuclei?

- CCN are subset of aerosols that act as **seeds for cloud formation**.

- **In-cloud supersaturations** (Seinfeld and Pandis, 1998)

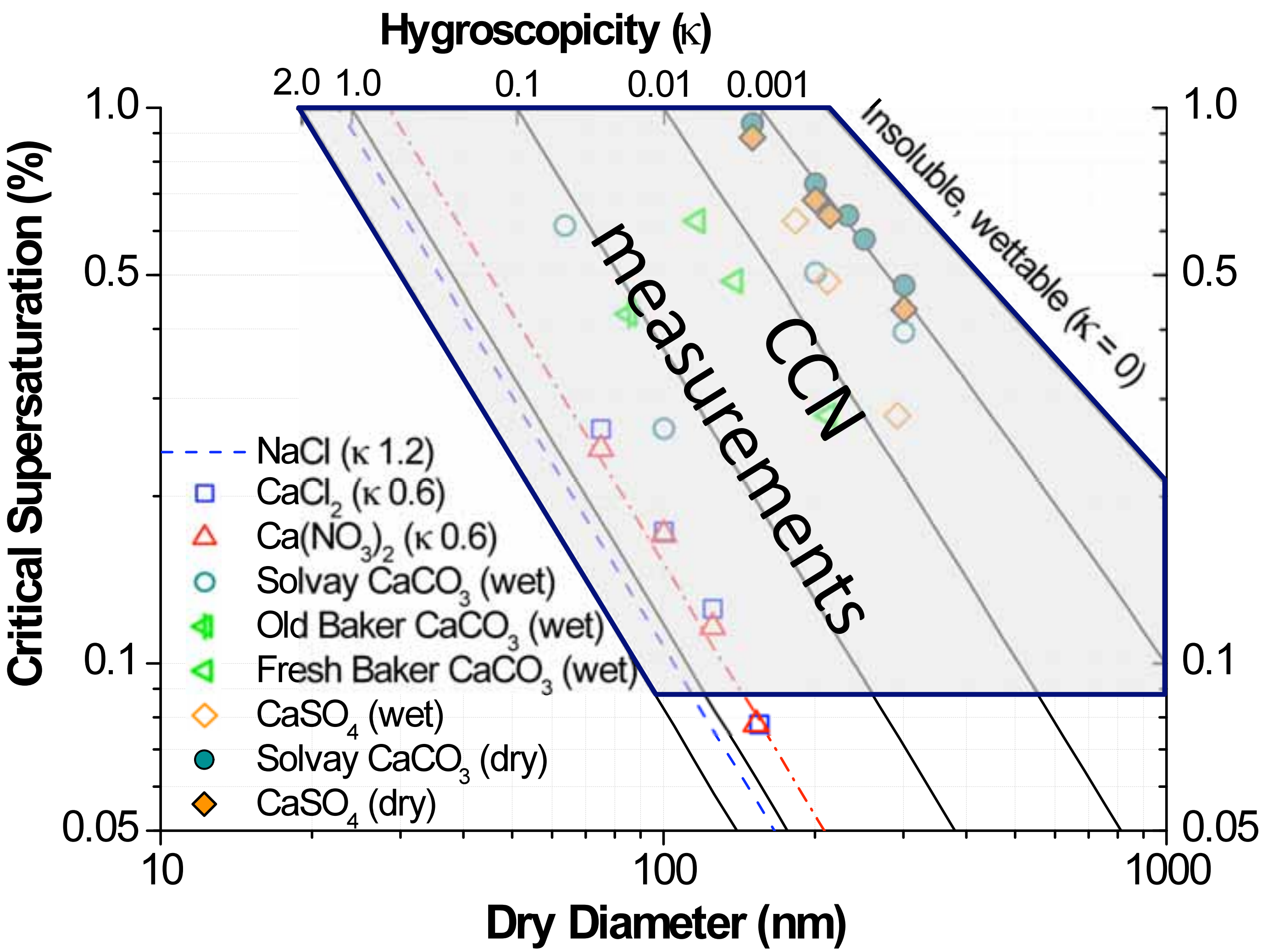
Continental cumulus	0.25 – 0.7%
Maritime cumulus	0.3 – 0.8%
Stratiform	~0.05%
Fog	~0.1%

→ CCN instruments measure link between physicochemical properties of aerosols and cloud microphysics (**CCN spectrum**).

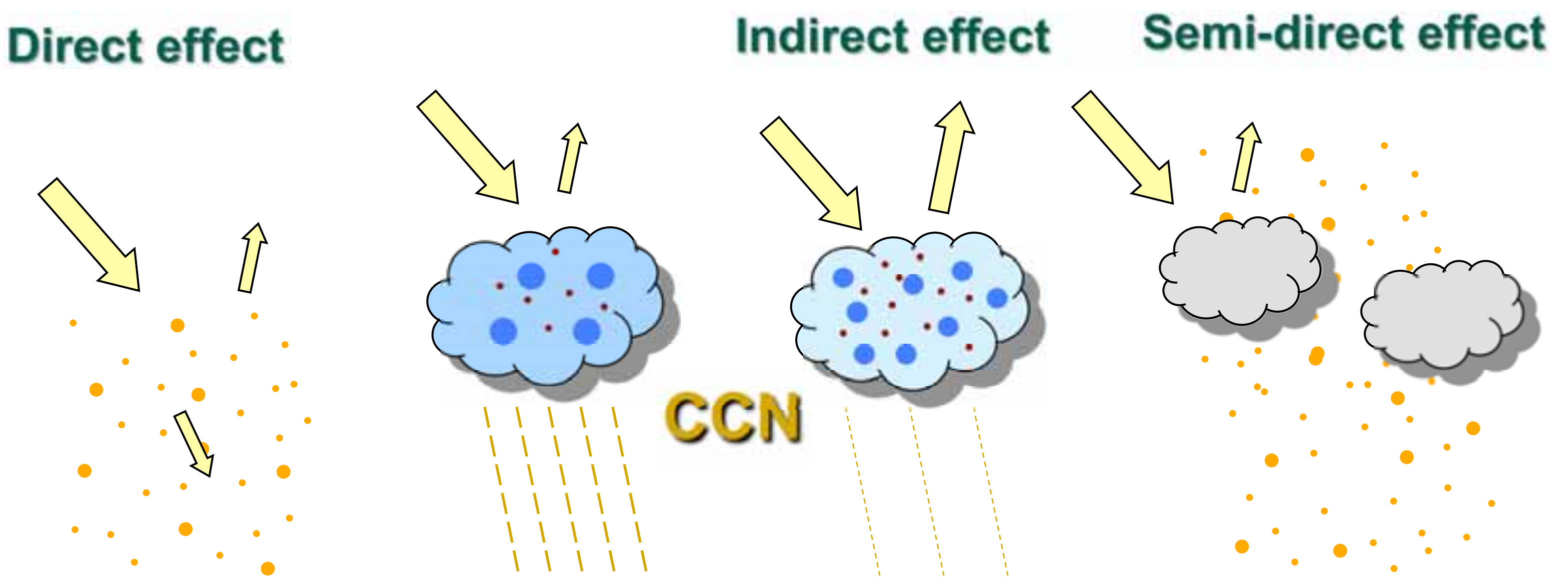


Cloud supersaturation affected by changes in CCN and updraft

Size and chemistry of CCN



Aerosol-cloud-climate effects

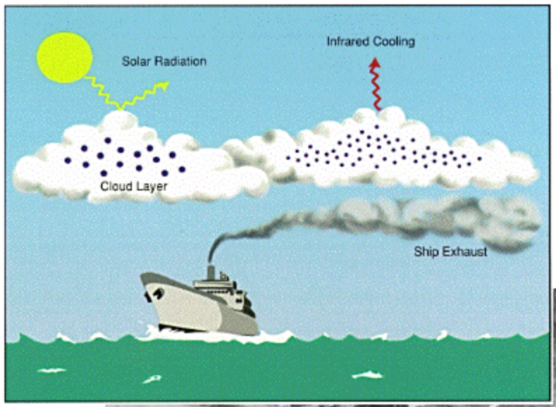


Scattering & absorption of radiation	Unperturbed cloud	Increased aerosols (CCN); suppression of precip. (Twomey et al., 1974; Albrecht, 1989)	Heating causes cloud burn-off (Ackerman et al., 2000)

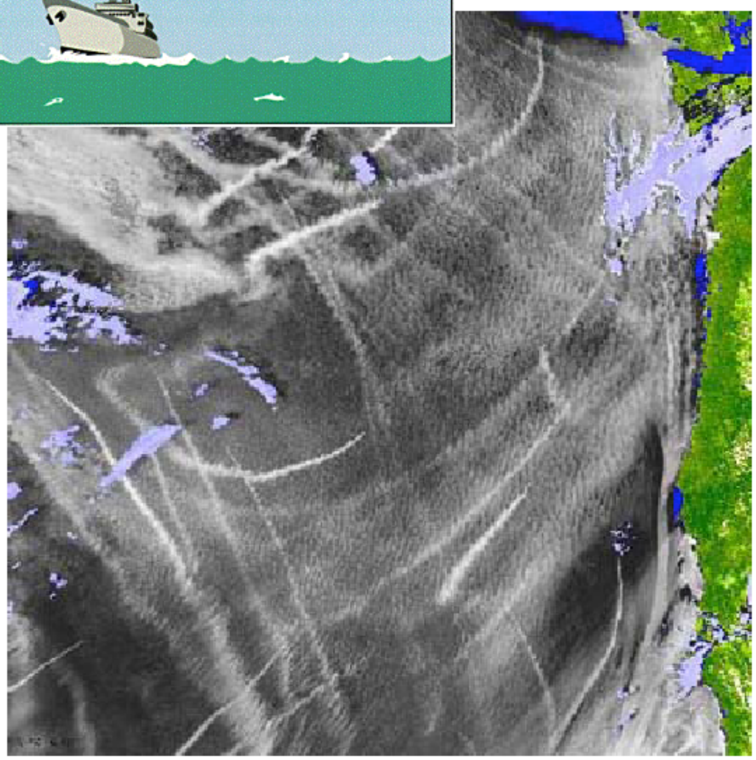
Adapted from 4th IPCC 2007

- Aerosols still **largest source of uncertainty** in global climate (IPCC)
- Generally considered to have a net cooling effect – but may also heat atmosphere (light-absorbing aerosol)

Aerosol Indirect effects



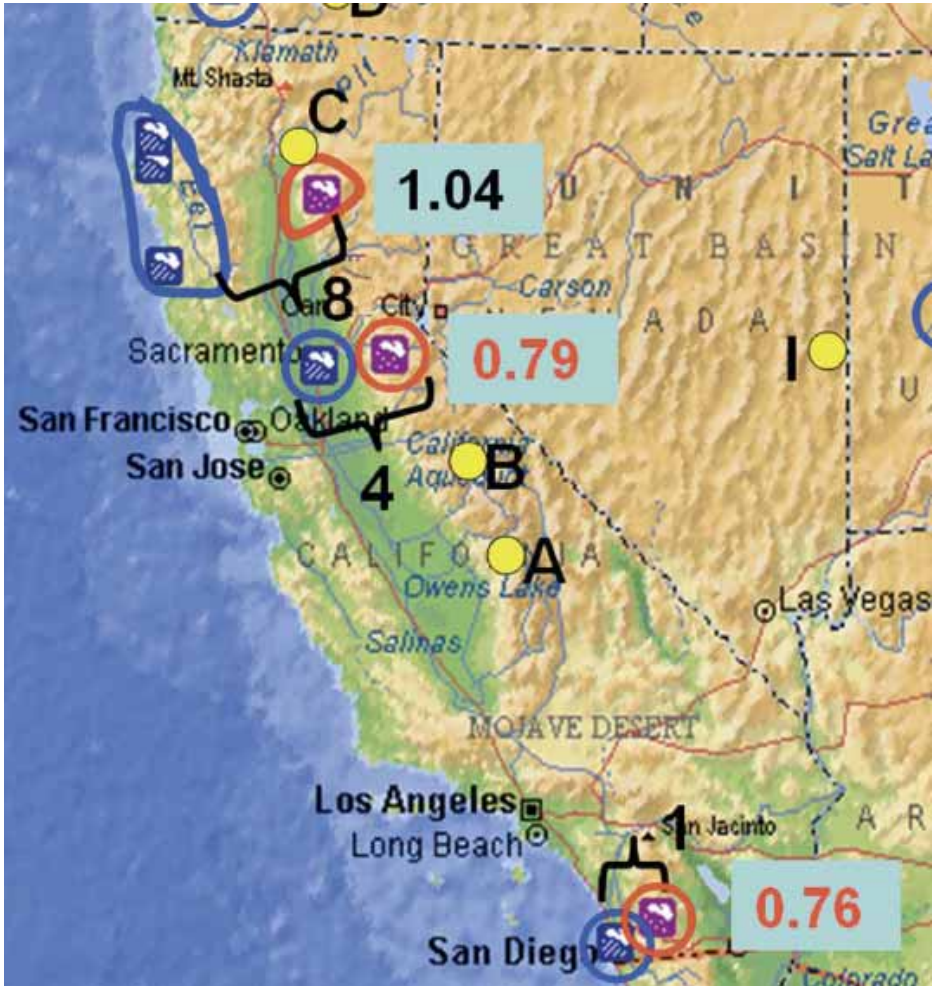
Twomey (Atmos Environ, 1974): *“it is suggested that pollution gives rise to whiter (not darker) clouds ----- by increasing the droplet concentrations and thereby the optical thickness (and cloud albedo) of clouds.”*



Increase in cloud albedo due to ship exhaust – classic example of aerosol indirect effect.

Satellite image of ship tracks off the western coast of the United States.

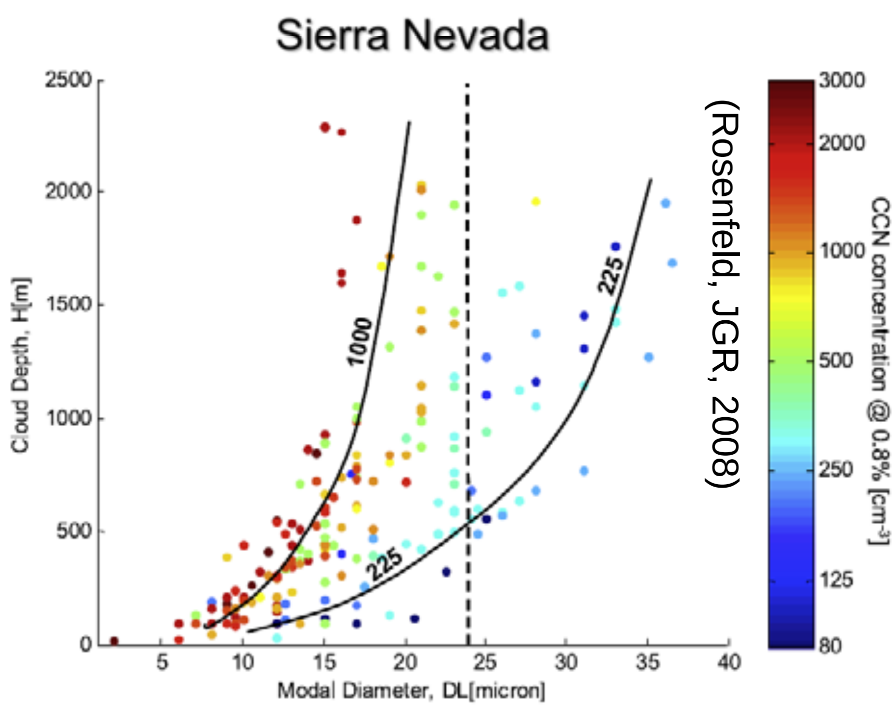
Suppression of precipitation

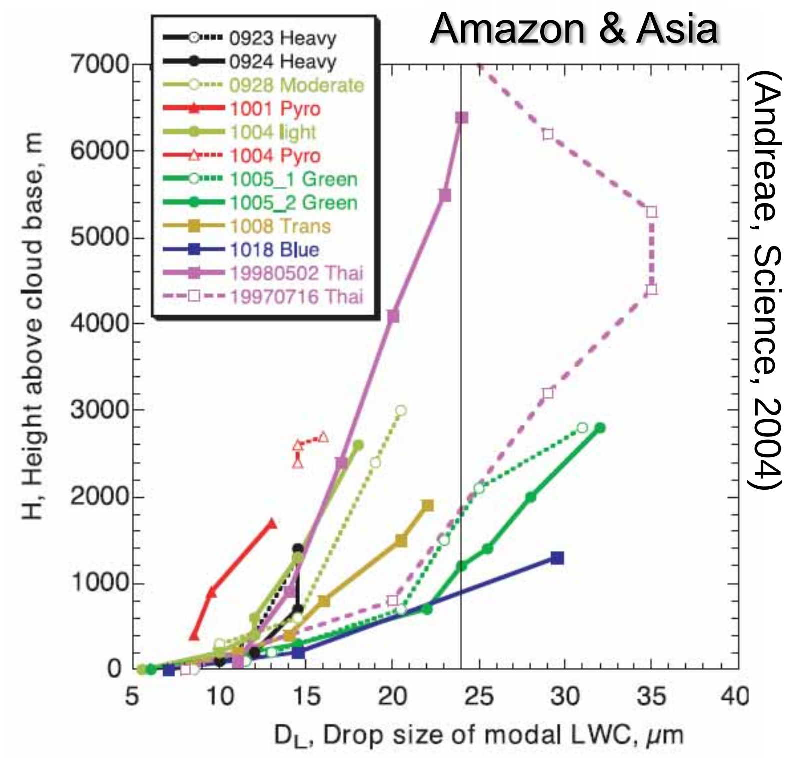


(Rosenfeld, JAM, 2006)

- Field studies indicate **<u>reduction in orographic precipitation</u>** downwind of urban centers
- Studies suggest that anthropogenic aerosols may **<u>shift and/or reduce water supply</u>**
- **<u>Large uncertainties</u>** in the role of anthropogenic aerosols on precipitation efficiency – contributions of **<u>meteorology and aerosols</u>**

Pollution & cloud-microphysics





- Studies in Sierra Nevada and Amazon found that **droplet sizes are smaller in polluted clouds** for a given height above cloud base
- Threshold for precipitation when **cloud droplet diameters ~ 24 μm**
- Polluted conditions slow the growth of cloud droplets **→ delaying the conversion of cloud water into precipitation**

CalWater 2010

- One of major goals of CalWater: How do **anthropogenic aerosols impact precipitation efficiency** and snow melt?
- CCN provide **the link between aerosols and clouds**
- Traditional measurements relate CCN number to supersaturation (CCN spectra) -- but **aerosol chemistry** related to CCN has been difficult to measure directly
- Our goal: New device to identify **anthropogenic**, **marine** and **biogenic contributions** of cloud-active aerosols
- Recent advances in technology and understanding **precipitation processes in California** are being combined in CalWater (measurements and modeling)

WCPC & CCN instruments

- water-based devices for creating droplets

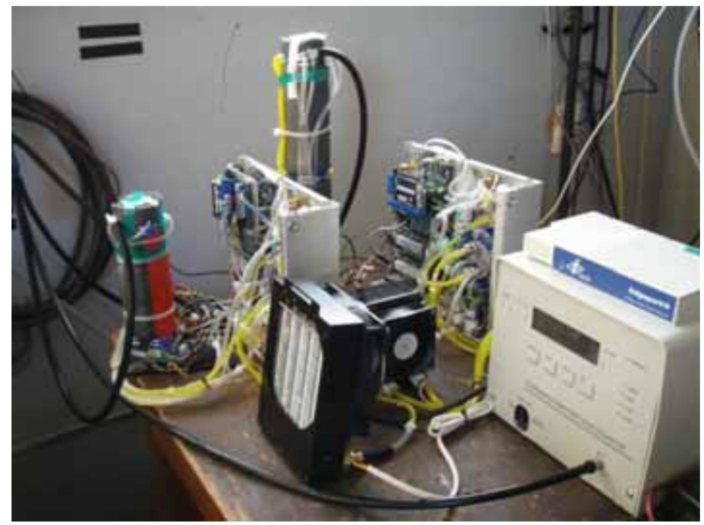
WCPC

Miniature ADI Water CPC

→ Total aeosol concentration

(D > 10 nm)

mCCN



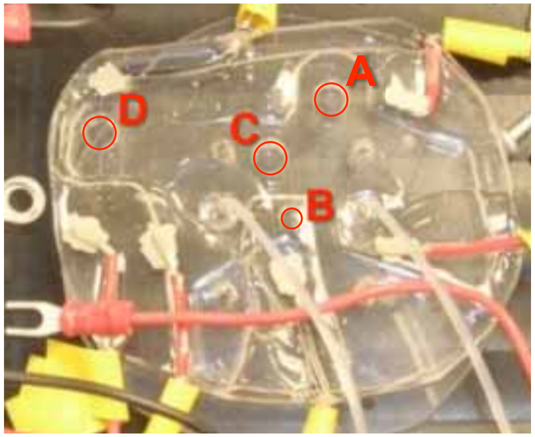
Miniaturize SIO CCN

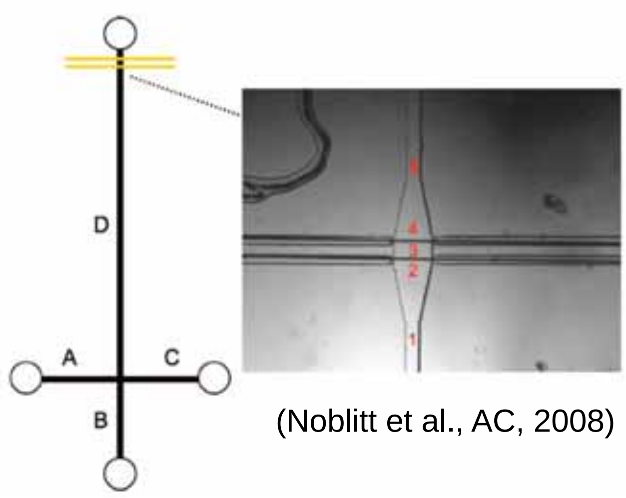
→ cloud-active aerosol

0.1% < S < 1%

u-Capillary Electrophoresis

- Dimensions:
  - Chip ~ 50 mm x 50 mm
  - Channels ~ 30 um (width of human hair)
- Sample volume ~ 30 uL
- Detection limit ~ 0.1 uM
- Separation of
  - Chloride (sea salt)
  - nitrate and sulfate (reactions of SO_2 and NO_x)
  - oxalate (secondary organic aerosol)



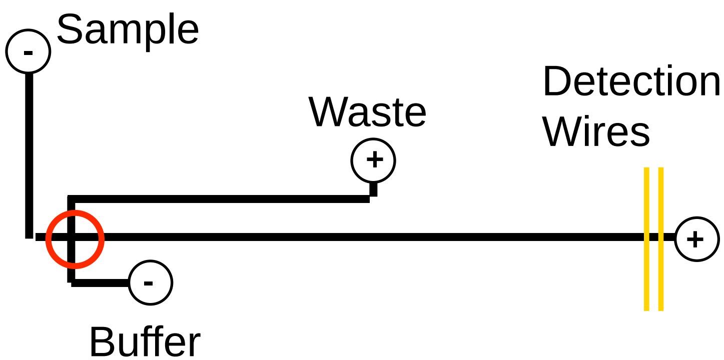


(Noblitt et al., AC, 2008)

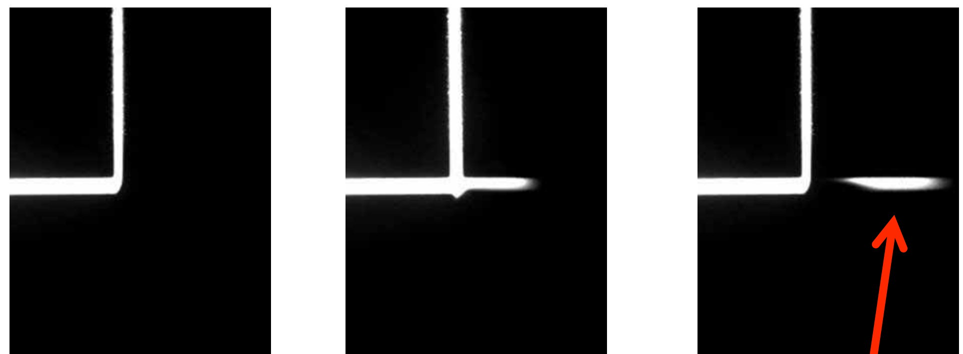
A: buffer
B : sample
C: waste
D: detection

Microchip CE Operation

uCE channel layout



Sample Injection

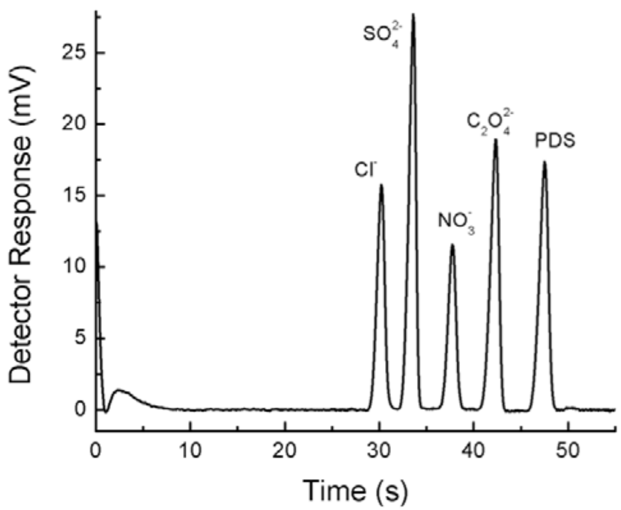


images by S. Noblitt

Before Injection **During Injection** **After Injection**

~ 1 nanoliter of sample injected

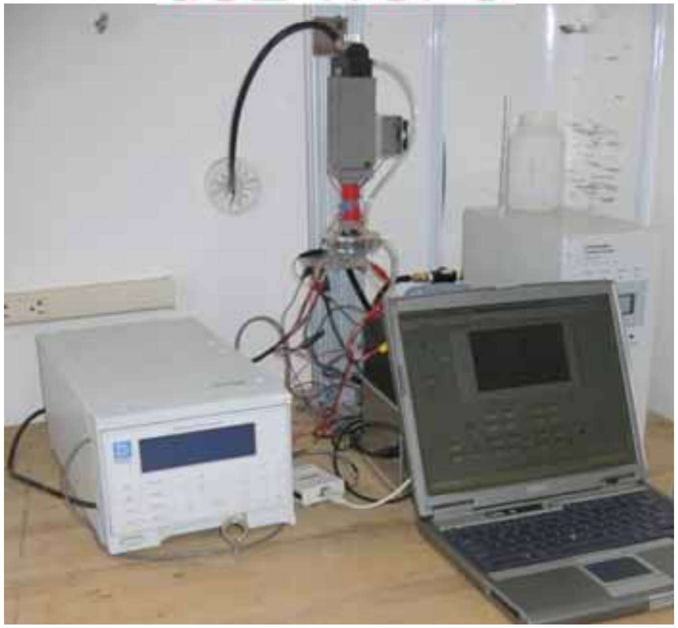
Representative Electropherogram



- Injections are performed by creating a voltage potential between reservoirs
- Detection by conductivity measurement

uCE-mCCN & uCE-WCPC

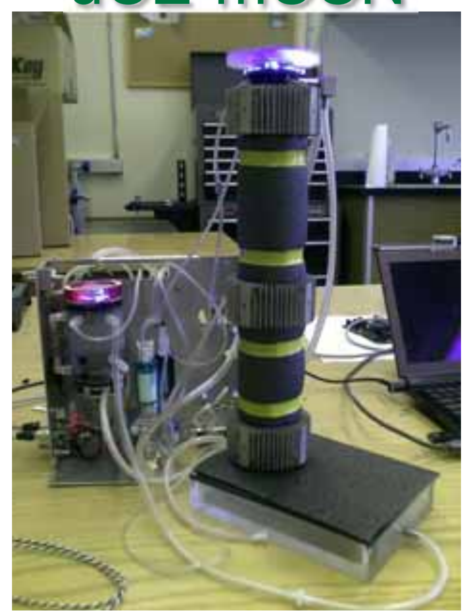
uCE-WCPC



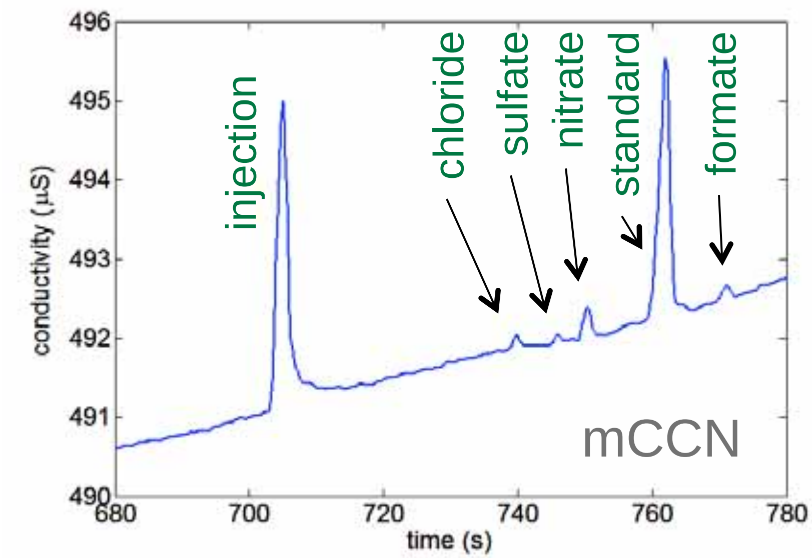
- Activated droplets inertially collected in a reservoir on the microchip.
- Sample injected into the separation channel for analysis.

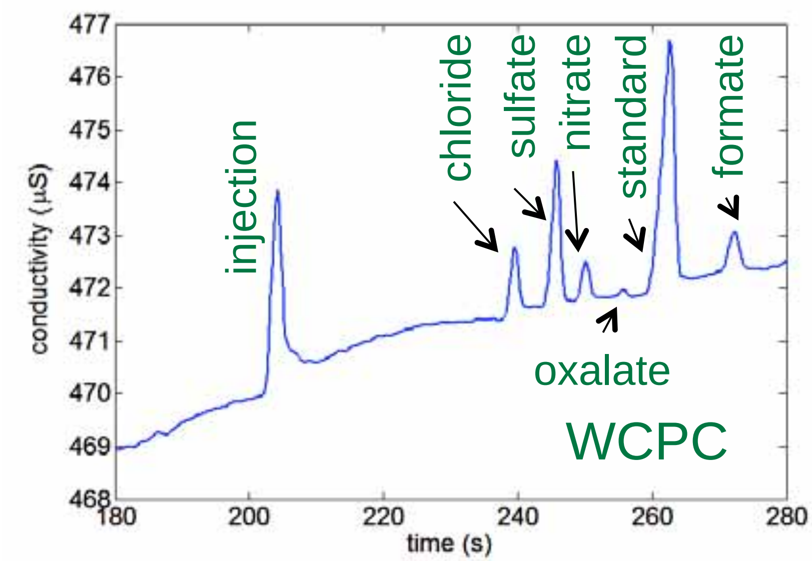
- Inclusion of an internal standard to convert measured solution concentrations back to aerosol/CCN concentration units (e.g., μg/m^3 of sulfate)
- Reservoir flushed to remove remaining sample and start new collection.

uCE-mCCN



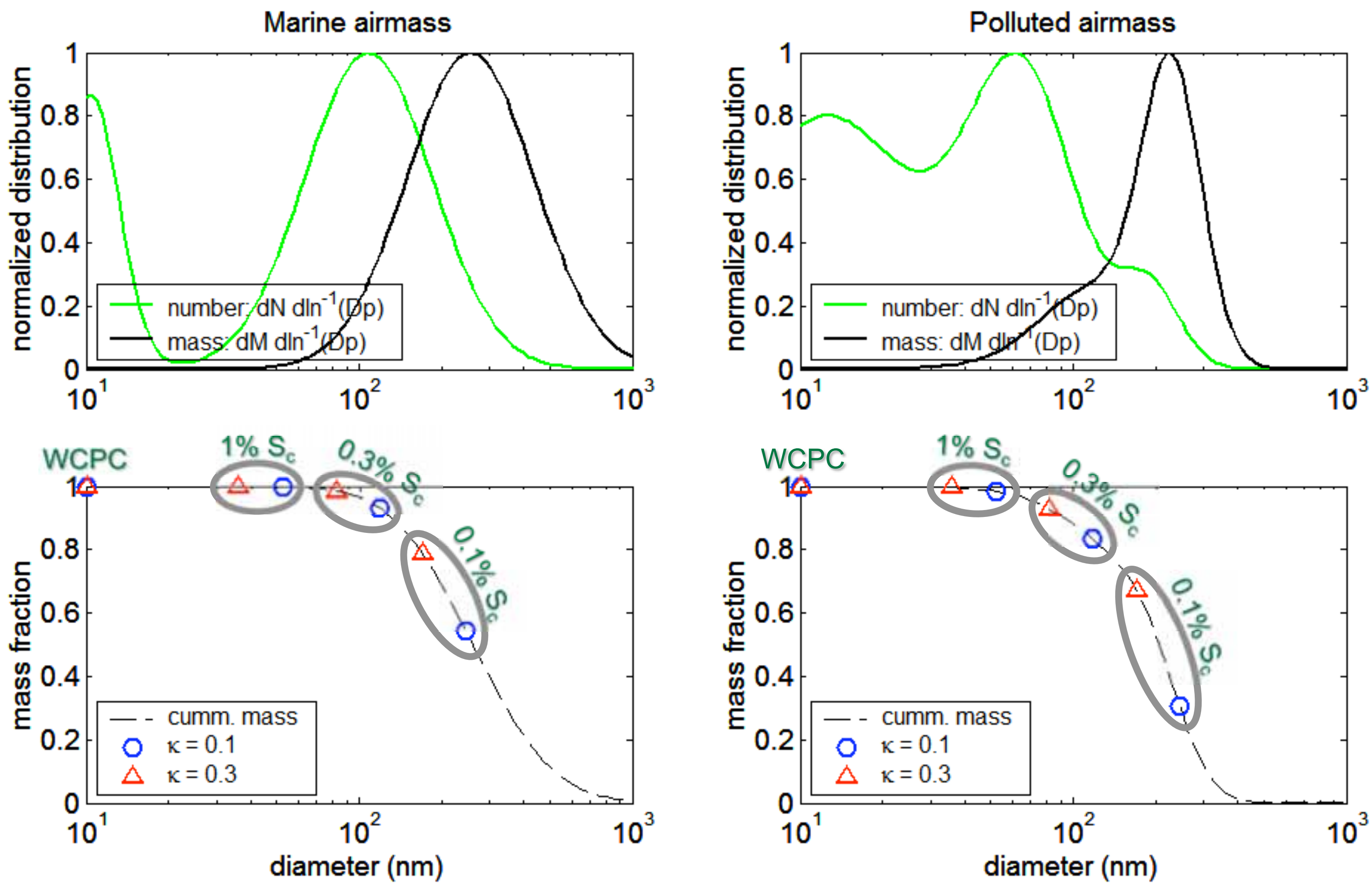
Results from CCN & WCPC - uCE





- First results show that CCN chemistry can be measured directly
- WCPC gives total mass for aerosol population (ref.)
- 45 min sample collection
- Collection done manually and transferred to uCE for analysis
- Outlook:
  - Testing/calibration
  - automation for CalWater campaign

Aerosol & CCN chemistry in clouds

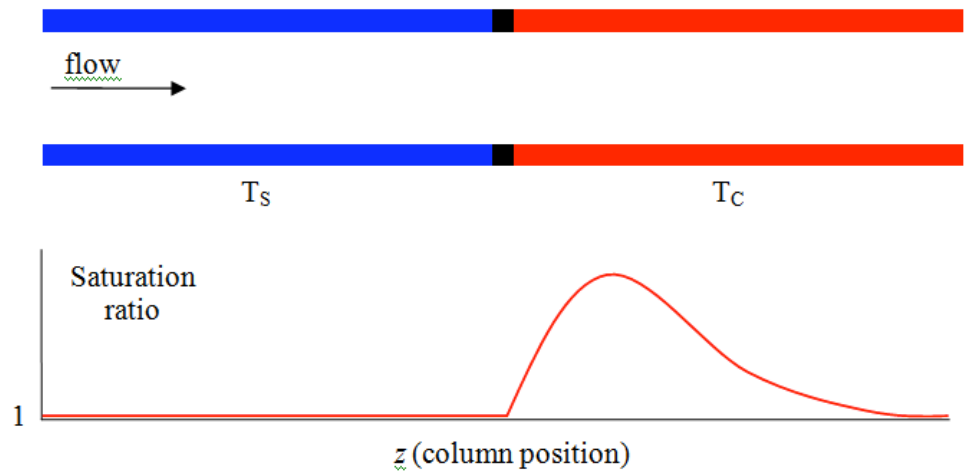


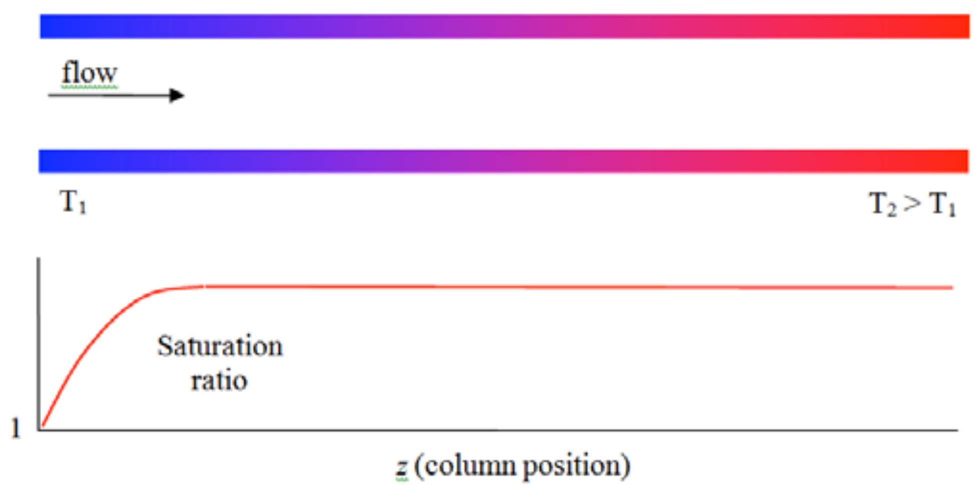
→ aerosol chemistry as a function of supersaturation gives **insight to chemical processes within clouds**

Contribution to CalWater

- Cloud condensation nuclei (CCN) basis for linking aerosols to **clouds & precipitation**
- First continuous ground-based measurements **uCE-mCCN and uCE-WCPC**
- ~30 minute time resolution of **sulfate, nitrate, chloride, and oxalate** in aerosols & CCN
- identify **anthropogenic**, **marine** and **biogenic contributions** of cloud-active aerosols in the Sierra Nevada and the fraction of soluble ions that serve as CCN
- In addition to uCE-CCN, **CCN spectra (0.1 to 1% Sc)** measured at two sites

WCPC & CCN instruments





Aerosol and CCN chemistry w/ uCE

Objectives:

- couple miniaturized cloud condensation nuclei **(mCCN)** & water-based condensation particle counter **(WCPC)** to micro-channel capillary electrophoresis **(uCE)**
- develop **interface to uCE system** for continuous, long-term measurements of cloud-active aerosols in a research network
- **measure water-soluble ions** (i.e., sulfates, nitrates, chloride and oxalate) to estimate the anthropogenic, marine and secondary organic contribution to CCN-active aerosols